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THE

ORIGIN AND CONSTITUTION

OF

SOILS.

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THE ORIGIN AND CONSTITUTION OF SOILS.

LECTURE BY PROF. WILLIAM H. BREWER.

In nature the living plant is adapted to the dead mineral world in which and upon which it lives and multiplies. The soil and climate determine where it shall grow, when it shall grow, or indeed if it shall grow at all. The native or naturalized plants growing wild in any country are those which Nature has moulded to the conditions of soil and climate there found, and if, from any cause, and through long ages, the soil or climate changes, the successive generations of plants must also change and adjust themselves to the new conditions, or else die out. Everybody is familiar with this general fact. We all know that apple-trees and hickories will not grow in Panama, nor cocoanuts in Connecticut, because the *climate* is unfit. We also know that apple-trees and hickories will not thrive in one of our salt marshes, because the *soil* is unfit. If plants in any way migrate from their native land to another with somewhat different soil and climate, those varieties which are too unyielding or fixed in their nature to change and suit the new conditions, are either sickly or entirely perish, and those which are plastic enough to be moulded into such shape as to fit the new home, survive and occupy the ground. This is a great law in nature, the mineral world can neither die nor perish, and the plant must adapt itself to the inexorable conditions.

But in agriculture it is just the other way. Nature can afford to work slowly, time is no object; but man cannot wait, he must be in a hurry. He can rapidly, easily, and greatly change the *soil*, the plant he can change but very slowly, and not greatly. Indeed, he can make a soil out of its constituent elements, if that be necessary, but he cannot make even the simplest plant. And thus it is that while Nature adapts her

crops to her soil, the husbandman can only adapt his soil to his crops,—the soil is the only element or condition over which he has control.

This process of adapting the soil to the plant, by tilling, manuring, draining, and watering, or, to use the general term, *cultivating the soil*, has been the leading vocation of civilized man in all ages. As it has been the subject of his labors, so too it has been the theme of an abundant literature from the days when writing began until now. How abundant this literature is, only those know who have attempted to collect it. Dr. Sturtevant here tells me he has a list of near six thousand authors who have written books or essays on agriculture in the English language alone. And then we have the reports of agricultural societies, experiment stations, and agricultural schools, the items in agricultural newspapers, and in the "agricultural columns" of the secular and religious press,—even to the paragraphs of the advertising almanacs that are flung into our doors at this season of the year.

In view of all this, in this lecture I can hope to add very little indeed that is absolutely new to this great subject. So many scientific men have been over this ground before so much fuller than I can, particularly Professor Johnson, in his book, "*How Crops Feed*," has treated this subject more completely than can be done in any lecture or any three lectures, that I am almost ashamed to again go over such old ground at such a time as this.

However, there is so much that is old to the community or to the race, but is new to each individual at some time, that has to be learned by each one for himself, that it may be profitable for us to review our elementary knowledge of the subject.

In fact, it is always profitable to review old elementary truths, and keep them present with us, because we never do so well as we know how. It is just so with moral truths also, —the ten commandments were given the race more than thirty-three centuries ago, and have been taught ever since, and there is room for them yet, for some farmers still swear, and some politicians still steal,—it would be worse if the old

truths were not continually preached into our ears. We must always keep on teaching elementary principles, whether it be in morals, science, or in farming, and this is my excuse for a lecture on *The Origin and Constitution of Soils*.

The crust of the earth is composed essentially of solid rocks, usually covered with a comparatively thin layer of soil. This soil is mostly derived from the solid rocks, mixed with partly decayed vegetable matter. The mineral matter of the soil, that which came from the rocks, has reached its present condition in a variety of ways. Rocks may decay by the action of the atmosphere, they crumble with frost, they may be dissolved more or less by natural waters, they may be ground up by ice, and they may be worn down by waves and running streams. All these agencies (and possibly others) have been actually working, some in one place, some in another, usually several of them acting together.

With the action of frost and moisture you are perfectly familiar. Water will penetrate the smallest crack or crevice, it freezes and expands, but little to be sure, but that little moves with almost irresistible force, and gradually the large rocks are split into smaller ones, these into gravel and then into sand, becoming ever finer and finer. But under the influence of air and water, the rocks decay in other ways than by freezing and thawing. Chemical changes and solutions take place, and rock may as truly rot as wood can rot. This goes on most actively in hot countries. We are told that in Brazil great areas are covered with a thick soil which is the result of decaying and decayed gneiss rock, and in Cuba some noted tobacco soils are the result of certain rocks thus decaying on the spot. This same process doubtless goes on here also. Geologists tell us that the so-called " demoralized rock " in the Hoosac Tunnel is but rotten rock. I have spoken of the *solution* of rocks by natural waters. This is a particularly interesting fact. Pure water itself is a strong solvent, but the natural waters on the surface of the earth contain air and carbonic acid, and sometimes nitric acid and ammonia, and perhaps other substances which modify its powers. Water containing carbonic acid dissolves limestone

and chalk, and rain water always contains it, and this slowly dissolves away even the hardest marbles. Prof. Whitney, the geologist, thinks that some of the prairie soils of Iowa, which are of the nature of an impalpable clay, are the residue of clay left after the limestone had been dissolved ; that once a thick bed of limestone covered that country, containing a small part of alumina or clay (I think only one or two per cent.) ; that the rains of centuries have dissolved out the lime, which has run down the rivers to the sea, leaving the clay and silica as an impalpable prairie soil. If rain water percolates through soil containing decaying vegetable matter, it takes up more carbonic acid, thus increasing its solvent power. Geologists tell us that the great caves in many limestone countries have been formed by such waters dissolving the limestone. More than this, those eminent scientists, the brothers Rogers, showed, many years ago, that other rocks than limestone, even granite, are decomposed by carbonic acid waters. The action of nitric acid in rain water, particularly in tropical countries, and ammonia, has often been discussed in this same connection. It would take a course of lectures to do justice to this part of our subject, and some phases will be alluded to again. That rocks may be worn down by the waves of the sea, and by running streams, is too well known to need more than mere mention here.

I have reserved to the last of these agencies, the grinding by ice. In many cold countries there are *glaciers*. These, as we now see them, are great streams or sheets of ice, moving slowly, but with irresistible force down the slopes, sometimes but a few inches per day, and never more than a few feet; in the Alps they move but one or two feet per day; but in the Arctic regions sometimes more than twenty feet. The ice is formed from the snow of successive years, compacted together until it becomes often several hundred, and sometimes even thousands of feet thick. As this moves over the solid rocks it wears and grinds them. We see this process going on in places now, in mountains and in high latitudes where the climate is cold enough. A theory, advanced by the great Prof. Agassiz, and now accepted by most scientific men, is, that a

great portion of the Northern Hemisphere above our latitude was once capped by gigantic glaciers. That these covered all of New England, and slowly moved southward, grinding down the rocks, and making the most of our soils. In this State this ice was thick enough to cover the highest land in the State; of this no one who has examined the subject has any doubt. The most of the soils of the State had their origin in this geological period, but of course have been modified since by the influences I have already spoken of. The broken and pulverized material lying above the solid rocks is known to geologists under the general name of *drift*. In this State it is more or less mixed with bowlders, many of which are scratched and grooved by old glaciers. However interesting it might be to follow this up, I must leave it with the remark that the very way in which such soils were made, this mixing up of the ground-up fragments of many rocks, has given greater variety to our soils, and greater general fertility, but it has prevented uniformity, so that often adjoining farms are very unlike.

In all these soils that I have mentioned thus far, there is a considerable difference between the upper soil and the subsoil. The upper part is more or less mixed with vegetable matter, and has been modified by atmospheric agencies.

When we take any ordinary soil and shake it up in water, the coarse sand and gravel sink quickly, the fine sand less quickly, while clay remains suspended in the water, making it turbid or roily. If this passes into a river, the swifter the river the coarser the particles that are carried along by it. A mountain torrent will carry along great stones, a swift stream gravel and sand,—very fine sand, called silt, is carried much farther, while clay settles but very slowly indeed. Now, when a stream swollen by floods carries along its burden of soil, it deposits it in accordance with these laws. If it overflows the banks, the coarser sediment is left nearer the banks while the finer is carried farther away. By some such process all *bottom*-lands are formed; it is easy to see why they are more uniform than *drift* soils. They are usually very rich from a variety of causes, but vary according to the coun-

try which furnished the original materials and the nature of the stream which transported them.

We may have a soil with but very little mineral matter, made mostly of vegetable matter, growing in water or swamps, and but partly decaying there. Peat swamps and some of our salt marshes are examples of this. Sometimes bottom-lands are a mixture of mineral and vegetable matter made in this way; peaty swamps are overflowed from time to time when the river is at flood, and sand, silt, or clay is left with the peat. Some of the most productive soils of the world are of this kind; the islands near the junction of the Sacramento and San Joaquin rivers in California, and the rich lands of Holland, are well-known examples. Holland supports a denser population, perhaps, than any other equal territory on earth, on her rich bottom-lands. Marly and chalky soils are so rare in this country that I can pass them by; but a word more in this place about clays. When on bottom-lands or in valleys, they are usually the sediment deposited from muddy water in some earlier age, but clays on hillsides are often, in part at least, due to the decay of slate rocks. You know its properties, its toughness, how it retains water, how it shrinks on drying, and how it may be kneaded when wet, and then is very hard on drying.

We have seen how the mechanical texture depends on the origin, and in popular language we class soils as stony, gravelly, sandy, silt, loam, clay, muck, peat. There have been various means devised to analyze soils mechanically, and classify them according to their mechanical texture. The most elaborate series of such analyses made in this country are those made by Prof. Hilgard of the soils of Mississippi, and he greatly extended our knowledge of those fine clays which remain long suspended in water, as I have spoken of.

Peaty soils may shrink on drying even more than clays. This is due to two causes,—first, the actual shrinkage of the dried material, and second, its oxidation or decay. When such lands are dried and brought into cultivation, the vegetable matter decays. When the Holland peat-bogs have been drained, they have sometimes sunk several feet in the course

of years, by such decay, and the same is true of the drained marshes in New Jersey. We have a similar case in New Haven, where the salt water was shut off from a salt marsh over a century ago, and it has since been used for pasture; the embankment was broken last year, and the tides now cover it like a lake, the land has sunk away from a few inches near the edges to more than two feet in the more peaty portions.

There is an intimate relation between the mechanical texture of a soil and its fertility. Stony and gravelly soils are usually warmer, and clays are heavier and colder, and sandy soils are easily tilled. It is probable that there is often an intimate relation between the fineness of a soil and the welfare of the crop it produces. I may illustrate this best by a striking example. Most of my hearers are aware that I have given much attention to the distribution of forests in our country, and so have studied the prairie question. Now, you well know that there are great areas that are naturally treeless. Some of these places are treeless because of drouth, others because of climate, some because of the chemical character of the soil; but we have vast prairies with fertile soil, genial climate, and abundant rainfall, which were naturally treeless nevertheless. One of our most eminent geologists, Prof. J. D. Whitney, after an extensive study of the subject on the spot, attributes the lack of trees on certain of the western prairies to the texture of the soil, that tree seeds do not naturally start and grow well in the very fine, impalpable soil, but where gravel comes in there trees appear. While this theory is combated by some writers (for there are many theories propounded), it is nevertheless in accordance with a great number of observed facts.

The chemical fertility of a soil depends essentially on its mineral composition, and as this is all derived from the rocks, a soil contains all the elements which the rocks originally did, usually, however, in different proportions and in different chemical combinations, and to this mineral matter is added certain materials derived from the air. I have already explained how natural waters act chemically; how, with the dissolved air, carbonic acid, nitric acid, etc., some minerals

are dissolved and others put into new combination. From the effects of these, with frost and other agencies, the chemical character of the soil changes from year to year. The particles crumble, and are often re-cemented again; that which was entirely insoluble last year becomes partly soluble this year, and it is only the soluble portion which can act as food for the growing plant. We generally associate the idea of much organic matter with rich soils, but this is not necessarily so. Some of the most fertile California soils I have ever seen, whose marvelous crops are the wonder of the world, have but very little vegetable matter.

The incessant chemical change which is going on in the soil through atmospheric agencies is one of the most interesting phases. As I have said, the hardest rocks slowly dissolve away, and water is the immediate solvent. When soils have become poor by too hard cropping, often a rest of a few years will, in a measure, restore the fertility. This comes from the decay of the insoluble part, which assumes new chemical combinations and becomes soluble.

If the original rock which furnishes the sand and gravel of a soil, contains all the mineral elements of fertility, such a soil may be impoverished by too hard cropping, but it cannot be *exhausted*, or, as you would say, *worn out*. The annual weathering, by making soluble what was before insoluble, is a process of continually restoring fertility to a greater or less degree. We are told of certain soils in Greece which have been cropped for thousands of years, and are still reasonably fertile, because of such changes as I am talking about.

A soil having this character in a less marked degree may be temporarily impoverished; we say then that it is in a low condition, or "run down," and yet it recuperates rapidly with rest, and with proper tillage or pasturage.

On the other hand, there are some soils that have great fertility for a time, and when they run down remain very poor indeed. Some of you have seen new soils show this by producing a few large crops and then failing. What fertilizing material the soil had was mostly in an available condition for plant-food, is used up by a few crops, and then barrenness fol-

lows. I have heard of some remarkable cases of this in the Western States, where the soils seemed wonderfully fertile at first, was rapidly settled up, produced a few large crops, then utterly failed, and are now abandoned. These first few large crops took up the plant-food which had been preparing for centuries. It was like a long investment suddenly becoming available in ready cash, which is as suddenly spent, poverty following in its track.

Not so here in New England. While our soils are not so fertile as some of those I have spoken of, they are mostly of a better kind of fertility; we can *impoverish* them, but we cannot *exhaust* them. This I think is one of the brightest hopes of our Connecticut farming. The investment may not pay so high an annual rate of interest as some others, but it is sure, and we know that the bank will never fail.

This slow but incessant chemical action of the atmospheric elements on the soil is, to me, one of fascinating interest, because I have studied it in so many phases, and because it has so many applications. Even in mining, old placers of tenbecome rich again through this weathering.

Some years ago I began a microscopic examination of different sands in connection with certain geological studies. Sands from the sea-shore in many parts of the world, from the shores of lakes fresh and salt, the wash of rivers, from placer mines, from mountains and valleys, the drifting sands of the Pacific slope, and from the deserts of the great basin, and finally the sands washed out from various soils, arable and otherwise. It is curious to see how some of those from soils have been modified by the influences here spoken of—often there is a partial cementing again, by which each larger particle is coated with smaller grains adhering to it; in others the splits and cracks by frost, and more interesting still, the way some show that they have been partly dissolved. Only this week I was examining some from a sandbank deposited in Central New York, near Cayuga lake, so long ago that a ravine four hundred feet deep has been worn in the rock since that sand was deposited. When deposited it was evidently all worn and rounded by the water which

left it where we now find it. Now each quartz grain is all roughened by little pits sunk into it by being partly dissolved in the long ages it has lain there. In another, from the old silt left near Niagara Falls before the gorge was made in its present shape, the solution of some ingredients has partially re-cemented others.

There are other properties of soils so intimately related to the constitution and composition, that I will allude to some of them—not all, by any means—while other interesting ones, particularly those relating to heat, light, color, conductibility, etc., I must entirely pass by.

The various properties of arable soils which have immediate relation to the use of manures are of special interest. You are familiar with that property by which manures are retained, how dirty waters are purified by being filtered thoroughly, putrefaction stopped or hindered, colors discharged, odors removed, etc. If stinking water is filtered through a soil, particularly a clay or loam, it comes through clear and sweet, —even the pungent odor of the skunk is removed by it. But these results are in reality due to several properties. In part to a fixing of some of the soluble parts, in part by forming new compounds, in part by oxidation, and in part in other ways. This matter of oxidation is a curious one. Wooden posts last very differently in different soils. As a rule, they decay quickest in open sandy soils, and last longest in heavy clays or wet peat. It is just so with all organic matters. It is well known that in some graveyards the human bodies decay in four or five years, in others only in fifteen or even twenty years. Now, this has an important bearing on the use of manures. In some soils the organic part of the manure disappears quickly, particularly in sandy soils, while in others, particularly loams and clays, they remain much longer, modifying both the chemical composition and physical character.

Again, soluble mineral salts are washed out unequally. As a general rule, those salts which are of most use to plants are held more tenaciously, while those that are injurious wash out easier.

There is another way in which the composition and constitution is affected by the air, that is, through the *climate*. Alkaline soils and salty soils of various kinds are only found in *dry* climates. All the saline and alkaline soils of the interior and western parts of our continent, and indeed of all countries (except shores) would be soon purified if the rains were abundant enough for numerous springs and streams. The countries are salt and alkaline because these salts have been developed by the disintegration of the rocks, and the soils have not been sufficiently washed out. Even our Connecticut coast salt marshes soon lose their saline character and become fresh if the sea water is excluded.

I have spoken of soils that were in a certain sense perpetually fertile, through decomposition of the rocky parts of it. There are other sources of perpetual fertility. With manure in suitable quantities and sorts, the fertility may be permanently kept up. This is so simple that it needs no further comment here. Again, by natural overflowings of water, a similar effect is produced. Of this, the valley of the Nile is the most illustrious example, where, from the very earliest antiquity, the soil has been kept fertile by the annual overflows of that river.

Of even greater interest and importance is perpetuation of fertility by artificial irrigation. There are abundant examples both in the Old World and the New, but I have been impressed with this anew by just reading the recent reports of an eminent engineer on the ancient irrigation system of Ceylon. This, called the "tank system," was on that island the growth of nearly two thousand years. It began in 504 B. C., rapidly extended about a thousand years later, and reached its height about 1400 A. D., when a population estimated at 20,000,000 was fed from these irrigated lands. The number of villages (many, however, mere hamlets) was over a million. The waters even of the heavy rains of that tropical climate were restrained by dams or "tanks," and used as needed. The same soil produced two crops of rice a year for century after century. Early in the fifteenth century came the conquest of the Malabars, and with it anarchy and mis-

rule; the "tanks" became broken one after another, the works fell out of repair, the population diminished to but very few; even now, after three-fourths of a century of attempts on the part of the British Government to bring up the country, there are yet less than two and one-half millions of people. It is believed that again, by the simple use of water, its old-time fertility will be restored, and from the operation of causes I have spoken of, may be almost indefinitely continued.

There appears to be a curious difference in some of the products of new as compared with old lands. I mean by old soils, those long cultivated. Those products which are formed directly in the plant are often and perhaps usually produced of great excellence on new lands. Thus wheat, of which the starch and gluten of the grain give the essential character to the flour; fruit, such as apples, grapes, peaches, etc., of great excellence; cotton for fiber, etc., are all produced of special excellence on new soils. But many products, particularly those which are a secondary product, not produced immediately by the plant, are better produced on lands long in cultivation. Thus, while *grapes* may grow well on new land, of fine flavor and in great abundance, yet *wine* of special excellence is nearly always from grapes grown on old lands; so, too, of tobacco, new lands often produce large crops, but the finer flavors (which are not produced ready-made in the plant, but are the result of a sort of fermentation) come only from old lands, so far as I know. Animals thrive well on new lands, but the best butter and cheese come from old pastures. I am told that sugar is produced most abundantly from crops grown on old lands; Allen tells us in his "Farm Book" that broom-corn on new lands does not yield so fine, tough, and desirable a brush as on old soils, and similar facts might be multiplied respecting other crops. These facts may possibly be due to a modification of the plants themselves, of the nature of local variation, but it is more probably due to some phase of the constitution of the soil as yet unexplained. I think that this part of the subject has not been much treated in the literature relating to soils, but many farmers speak of

subduing the soil in a wider sense than merely bringing it into tillage. I have long heard the word so used. It may be that this is after all a *very* old idea, dating back to the time when the first human pair were blessed and told to "replenish the earth and *subdue* it."

I have spoken of some of the relations of water to the soils, passing over other relations of great importance, I will allude to only one more, and give some observations which are, so far as I know, new.

I have already spoken of the fine materials suspended in turbid waters, and told you how that the settlings of the finer part makes beds of clay. Any solid material, if fine enough, will remain suspended for some time in water, and some of them, when the particles are very small, say the one-twenty-thousandth of an inch in diameter (and so on smaller until the limits of vision with our microscopes is reached), are in incessant motion, like minute living creatures. Pulverized charcoal, pulverized rock, fine particles found in soils—in fact, a great variety of substances in very minute division, show this phenomenon. These movements of minute particles are called by microscopists, "Brownian Motions," after their discoverer. While long known to some microscopists, it is only of late years that they have attracted much attention, in fact, so little were they known a few years ago, that many tolerably expert microscopists have mistaken them for living "animalcules." This year, while making observations in these "Brownian Motions," and trying to study up what was known on the subject, I found that a French chemist had stated that these motions of certain substances retarded their settling in water. And he explained the fact that certain impure waters in France, containing sewage, was better than pure water for some manufacturing uses, because, as he said, the sewage stopped these "Brownian Motions," and thus cleared the water. Without here giving the details of my experiments, or discussing the truth of his theory, I will only give such observations as bear directly on the subject of soils.

It has long been known that certain mineral salts dissolved in water hastened the settling of its suspended turbidness.

When a river, like the Mississippi, bearing much mud suspended, reaches the salt water of the sea, the mud then soon settles to the bottom, a fact well known to students in physical geography. In the analysis of the fine soils of Mississippi, Prof. Hilgard proved that clay which would require weeks to settle, could be rapidly reduced by the addition of a little salt brine. Or let me give a more striking example. I pulverized some of the hard soil or soft rock (which ever you choose to call it), from the "bad lands" of Wyoming Territory, early in 1875, washed it well with pure water, and then divided the lot into two test tubes. Into one I put a little salt brine, and in less than an hour the upper half of the test tube was perfectly clear. To the other test tube only pure water was added, and it was more than a year before there was any clear water at the top, the tube was but loosely stopped, and the evaporation from the surface was more rapid than the settling of the sediment. I then stopped it more securely to prevent evaporation; and now, after two years and ten months, there is less than half an inch in depth of clear water above the turbid portion. An hour's quiet, with a little salt in the water, would have more effectually cleared the water of its turbidity than has the thirty-four months without it. Many salts, both those found in nature and in art, produce the same results, and many natural phenomena, such as the proverbial clearness of the hard water of limestone countries are thus explained. Many experiments are recorded as to this property of mineral salts. On the other hand, it has long been known that many organic substances have the opposite property, and prevent the settling of fine particles. For example, many inks owe their blackness to fine solid particles suspended in a fluid to which sugar or gum is added. The settling then takes place very slowly indeed, unless by mould or freezing the chemical character of the fluid is changed, when the material is rapidly deposited.

Some time ago, I took various soils, shook them with water, and then experimented with the turbid portion that remained at the top after standing a day or two. Very finely pulverized charcoal, which remained suspended for many weeks

in pure water, if a very little dilute sewage, or dilute barn-yard drainings, or solution of peat were added, would be cleared in a few days, the suspended material settling in a granular-flocculent sediment at the bottom. This was tried over and over again.

I have here in these two bottles another illustration easier seen by the audience (this and other examples were used, to illustrate the lecture as given). A very red soil, from the Holy Land near Jerusalem, when shaken, requires eight or ten days to settle and leave the water clear. With the weak sewage it completely settles in a day, and you see plainly the difference between the two bottles standing since this lecture began, not yet an hour. I have repeated this many times, and in various ways, always with the same results. The sewage I have used was made by taking some of the deposit from an overflowed sewer, soaking it in water three or four days. The solution was but slightly colored, and had a very faintly stinking odor. The "dung juice" was the drainage from a barn-yard, weakened with many times its bulk of water. The "peat juice" was made by soaking peat in cold water for a few days. In all cases, the fluids were filtered over and over through the best filtering paper used by chemists, until the solution was absolutely clear, so far as could be seen by either the naked eye or the microscope. Each of these solutions were much more viscous than pure water; when pure water was shaken no bubbles were left on the top, while with these, fine bubbles would remain some time, in some cases for eighteen hours. We would have reasoned that such fluids, like the gum or sugar in inks, would favor the suspension of the solids rather than hasten its settling. I will not detail all the experiments, to do so would require a lecture. I will merely give a few more examples.

Here is some soil from near Hartford (in this State). I know not how long it takes to settle; the most of the solid matter will settle in an hour, but specimens are still slightly turbid after standing twenty-eight days.

With either of the fertilizing fluids spoken of, it settles clear in a few days.

Pulverized pummice-stone leaves a milky sediment behind when shaken in pure water, which requires several months to become clear, but the sewage cleared the fluid in a few days.

A calcareous clay from Northern New York would remain suspended in pure water for two or three weeks, but would be cleared in as many days with the sewage, etc. The experiments were extended to soils from other places, from the West, etc., *and in every case the main facts were the same;* the behavior of the different soils differed in degree, but not in princ ple.

That soils purified putrid waters when filtered through them, has long been a familiar fact; that putrid waters so act on suspended matter is, I think, new, except so far as the French observations go on waters for manufacturing, alluded to. Diluted putrid urine I also tried, with the same effect, but as this material contains more mineral salts the experiments were not extended. The chemist might at first think that possibly all the results I have spoken of might be due to the mineral saline matters dissolved, but while in some cases they doubtless aided in the result, in others the phenomena could not be so accounted for.

It is probable that this action is due to several causes. The saline part of the solution effects a part, then it may be that some organic salts may work in a similar way. Again, where the suspended matter is mostly clay, a compound similar to what is known to chemists as a "lake" is probably formed, and a part is doubtless due to some change in the physical texture induced in the suspended matter. The sediment was usually of a more granular-flocculent character than the sediment from pure waters.

It is probable that these facts are intimately related to various actions and reactions that take place between the soils and manures, but precisely how and what, I will not speculate upon. I noticed, moreover, that in several cases, when vessels (cylindrical glass-stoppered bottles) in which these experiments were conducted, stood in the bright sunshine, gas-bubbles formed more freely on the surface of the fallen sediment in the specimens with sewage and dung-juice, than

on those in pure water, but what was the nature of these bubbles, or whether the fact had any significance, I made no further experiments.

Other facts are suggested pertaining to these experiments. It is a popular belief that the muddy waters of the western rivers are very wholesome as drinking-waters. It seems to me that this may be so; that the putrid substances that come into the river may be rapidly carried down out of the way by the suspended mud which is in great excess. Again, some of the most unwholesome waters in wells poisoned by sewage are very clear and sparkling. The famous "Broad Street pump" of London, classical in sanitary literature as the well which killed over five hundred people in a little while from specific cholera contamination from a cesspool, was noted for its transparent and sparkling water. It seems to me eminently probable that sewage contributed to the clearing of the water without disturbing the invisible germs which produced the disease.

In the mutual relations of these finer particles of all arable soils and water and the atmospheric elements, and again between these and our crops, there is room for any amount of study and investigation. I am happy to say that some of these problems are now under investigation at the State Experiment Station, but there is room for many experiment stations to work.

Mr. BEARD of Danbury. I would like to ask the Professor if he can account for the fact that the water of the Missouri river, which is always roily, will freeze clear?

Prof. BREWER. Water that is impure generally freezes clearer. You know that in the Arctic regions, the salt water that freezes over is not as salt as the water underneath. Freezing is a process of crystallization, and when things crystallize, they are apt to crystallize out purer. We get salt out pure from sea water, and yet that sea water contains other things. There is a tendency in crystallization to eliminate impurities in that way. That Mississippi water, which is so muddy, is an illustration which came up rather in connection with this idea. It seemed to me an indication of the reason

why it was so healthy to drink. Some men out West say (I cannot vouch for the truth of it), that they have drunk that muddy water until their stomachs are almost like a stone jug. Still, it is called healthy.

Mr. White. I would ask Prof. Brewer if this freezing clear is not owing to the fact, that when water gets down to the crystallizing point, it absolutely rarefies the crystals, and that makes it lighter, while the mineral matters in water, like salt, do not rarefy, and in consequence of their weight will more readily leave it.

Prof. Brewer. Fresh water expands just before it freezes, but shrinks as it cools down to 39½ deg., and again expands up to the freezing point, 32 degs. That is not the case with sea water, which continues to shrink down to its point of freezing, 27½ degs.

Mr. Gold. Mr. White's idea that the rarefication of the water at the surface causes the impurities to sink to the bottom does not hold good. Many cases of crystallization occur at the bottom of the liquid: sugar crystallizes at the bottom, and still the crystals are pure, the impurities being separated by the process of crystallization.

Prof. Stockbridge of Amherst, Mass. I wish simply to ask Prof. Brewer a question, which will be appreciated, perhaps, if I make a remark first. He has stated that one of the very remarkable and very important properties of our soils was their retention of fertilizing material which was prepared and readily available for crops; that they retain salts, they retain organic nitrogenous materials; and yet, at another point further on, he said that in the end a large amount of valuable materials is washed from the soil, because the amount of rain falling upon the soil is vastly more than the amount of evaporation from the soil; there is a great deal more water passes through our soils (if I received the right impression) than evaporates. That is, the largest proportion of our rain-fall goes through the soils, and carries more or less of the fertilizing material with it.

Prof. Brewer. You misunderstood me; or if I said so, I

do not wish to be understood so. I said a large proportion. What proportion, differs with the soil and with the locality. The amount of water, for instance, which runs down the Ohio river, in proportion to the rain-fall on the river. is vastly more than the amount which runs down the Missouri river in proportion to the rain-fall on that river.

Prof. STOCKBRIDGE. Have you been familiar with any experiments which show what proportion of the rain-fall during an entire year is filtered through the soil, and what is taken into the atmosphere by evaporation? I do not know whether those experiments have been tried at your station or not.

Prof. BREWER. Not at our station. I merely know of the experiments that have been carried out by Dr. Sturtevant. The relative amount that runs through the soil varies under the different circumstances. Nitrate of soda runs through.

Prof. STOCKBRIDGE. Does the Professor mean nitrate of soda or nitrate of potash?

Prof. BREWER. Nitrate of soda. This salt will be washed out quicker than some other materials. In Nevada, there is a little lake where you will see a little pile of carbonate of soda, which has been raked out of the lake along the shore. Where soils have sufficient water, the alkali washes out. On the other hand, it has not been found that irrigation washes out many of the most valuable materials that plants take up. Nitrate of soda is one that is valu able that is washed out.

Prof. STOCKBRIDGE. If I understand you, you have said that nitrate of potash will not wash out.

Prof. BREWER. I do not say that. I don't know whether it will or not. I should rather think it would, from the fact that nitrate of soda will, but I don't speak of it as a fact. I say nitrate of soda will. A little of the salt is retained, but more runs through than of most other materials.

Prof. STOCKBRIDGE. Most of those materials do not run through, I suppose, until the soil gets saturated beyond our ordinary idea of fertility?

Prof. BREWER. Yes, sir, a good deal more. I have the

misfortune to be on the Board of Health of our city, and we have a sandy soil, and one man will have a well, and another man will have a cesspool, and there is a good deal of discussion on the question how far the materials from one man's cesspool are carried into another man's well. It is a pretty important matter to people who live in our large towns and cities. This much, however, I may say, that Prof. Johnson has carried out some analyses that would seem to show that oxidation of such materials goes on pretty rapidly in light, sandy soil. I wish we had the money means to carry on a series of observations in regard to this question, which would be of exceeding interest, incidentally, in agriculture, and which would be of vital importance in a sanitary point of view. The observations we have made would seem to show that where the use of cesspools has ceased, oxidation goes on with great rapidity on the materials which have accumulated in this sandy soil. There are many places in Europe where they have only a limited space for their graveyards, and the remains are removed after a certain number of years. It varies in different cities. I have known some places where it was five years; others, seven; and others, fourteen. In the vicinity of Paris, the common people are buried in a large grave, this grave being a great trench, four and a half or five feet deep, and wide enough for two bodies to be put in side by side. The dirt is thrown in upon them, and decomposition is complete enough in five years for the grave to be used a second time. There are other places where the time required is considerably longer. It is generally found that the light soils carry on this decomposition more rapidly than heavy soils. In such cases as that, it makes very thorough tillage. There is a tremendously rank vegetation. The evergreens and other trees that are set out there probably profit by the decomposition.

Mr. SEDGWICK. Do you attribute the fertility of irrigated land to the elements which the water carries upon the land or to the power of the water itself?

Prof. BREWER. I can only give a guess on that. I know that in some cases there is a slight manuring along with the irrigation. In other cases, I am inclined to believe (this is

a mere belief—I have no proof of it) that the conditions are such, that the natural elements of fertility in the soil are rapidly brought into available form.

Mr. SEDGWICK. For example, we know that in Colorado, where their soils are irrigated with almost pure water, snow water, the fertility of the soil is not developed until certain elements are, as you may say, taken up by the water and washed out.

Prof. BREWER. That is where the soil is alkaline, to begin with. In California, I have known soils that would not produce anything; they apparently contained alkali, and after being washed a little while, it would seem as if the deleterious substances were washed out, but by this peculiarity of which I have spoken, the materials of more immediate use to plants are retained. The waters, more particularly in the streams which come from the Sierra Nevada, are very pure indeed.

Mr. HUBBARD. The texture of the soil in a state of nature determines the character of the plants which will grow there, especially on the prairies of the West. From the impression which I derived from my experience in the West, I am inclined to differ somewhat with the Professor, though I would not set my authority against his, if he has considered the subject. I would ask whether the view he has put forward is merely his speculation?

Prof. BREWER. I have not made any extensive examination of the prairies myself. I put it forward as the theory of a person who, as I have said, examined the matter very extensively in a number of States, being occupied every summer in geological surveys for many years in those States. I have inquired of various persons in Iowa, and they all, without exception, told me that they found no native timber where you find this impalpable soil, free from pebbles, away from a stream, you do not find trees.

Mr. HUBBARD. Is it not a sufficient explanation of that to say, that wherever trees are protected from the destructive effect of fires, they flourish and grow? I have lived on those prairies between nine and ten years, and wherever young trees

were planted and protected from fires, and wherever there is natural protection from fires, the growth of trees is very luxuriant. Not only along the bottoms which you speak of, as, from the protection which the streams furnish against fire, would be expected, but in the open prairies, the growth of the cottonwood, burr-oak, hickory, hackberry, walnut, and elm is very luxuriant indeed.

Prof. BREWER. I infer that was either in Kansas or Missouri.

Mr. HUBBARD. It was in Kansas.

Prof. BREWER. Not in Iowa?

Mr. HUBBARD. It was not in Iowa, but I suppose the prairies are similar in Kansas and Iowa.

Prof. BREWER. They say not. There is no question that the influence of fires has had a great deal to do with it. But where the prairies have been protected from fires, in some places, the trees do not start. In the very places which I have spoken of, where there is no natural vegetation, trees when planted and started for a year or two, do grow well. But they do not start of themselves. It seems to me that there is some relation between the texture of the soil and the fact that trees do not start there without man's help.

Mr. HUBBARD. I suppose it is generally understood that the treeless plains were not always in the bare and naked condition they are now. I have been told that some portions of them, since they have been known by the white man, have been largely occupied by trees, that are now entirely barren of any tree life.

Prof. BREWER. I think you can travel a thousand miles west from Chicago, and you will not find such a thing as we called a "cradle-knoll" in New York, showing that trees have been blown down.

Mr. HUBBARD. I am speaking of the bare, arid plains of the West, particularly as far west as Fort Laramie, at the junction of the Laramie River and the North Platte. I have been informed, on what I supposed to be good authority, that people have known the time when there were growths of

timber there; and there are many things of this kind that militate against the theory that the texture of the soil determines this matter. I was inclined to think that there must have been a period when the rainfall was much greater than it is now, and when the influence of fires was much less, and that these two things affect it more than the texture and composition of the soil.

Mr. WEBB. The theory advanced by Prof. Brewer is one that never occurred to me until he suggested it; but upon reflection and comparison of my observations upon those prairies, I think his assertion is entirely correct. I never saw a black-jack growing either in Missouri or Illinois, or on the plains of Kansas, except it was on a gravelly hill. Prof. Brewer referred particularly to those plains which have not grit enough to scour a plowshare. It is gravelly soil after you get a hundred miles west of the Missouri River; what you would call a gravelly loam almost entirely. I think the Professor's observation is correct. It conforms entirely with my observation and my recollection.

Mr. FENN. Do I understand the Professor to say, that on none of the open prairies of Illinois do trees start?

Prof. BREWER. No, sir. I say there are a great many places where they do start, where they are protected from fire. I said that I have heard one eminent scientific man, who for years and years had worked on the prairies of Iowa and Illinois, with his eyes on that very fact, a man who has geologized in every State of the United States except two, who for more than thirty years was occupied in government surveys of some kind, generally geological, in the western country,—I have heard him say, within a year, that, if he was a betting man, he would bet five to one that, if he was blindfolded and taken out at midnight on any soil in the State of Iowa, and allowed to feel of it and take it between his teeth, he could tell whether that soil was forest-clad when the whites came there. I did not say that was my observation. I have never traveled through Iowa, except in the cars, and although I am rather a silent man, I did pump some Iowans on that subject. For about two years, while I

was preparing an outline map of the United States for Congress, I looked out persons familiar with the West, surveyors, persons who had been on exploring expeditions, railroad engineers, farmers, anybody who pretended to know anything about it, and asked them to tell me what they knew about that region,—how much land was covered with timber, what was the character of the timber, the character of the soil, etc. I may state that there is a great variety of opinion existing in regard to the origin of the prairies, and the whole thing has been befogged also by interested parties, railroad speculators, etc., who have land for sale. I have no doubt that on the fertile plains of the West, except where too dry, they will be able artificially to raise timber. The only reason why I brought this matter of trees up now was because of its relations to texture, and from the fact that many men have examined it who are chemists and geologists, and have come to the conclusion I speak of regarding the *texture* of the soils of some of the prairies. I do not claim that all the treeless regions of the West originated in that way. Dr. Bacon tells me that the sandy plains of New Haven were only partially clothed with trees at the time of the early settlement, and they are not of impalpable soil; we can say that on soil of such impalpable character that it will not scour a plowshare, trees do not grow naturally.